PLEA 2015
BOLOGNA, ITALY
09 -11 September 2015

How Not to 'Live Your Life in a Jumper'
Legacy of HVAC and the Curious Case of Comfort in Passivhaus

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

Research summary

Since the 1970s, the comfort model has experienced a major paradigm shift from PMV/PPD to the 'adaptive comfort' model (de Dear et al., 2013). As opposed to considering buildings as 'environmental capsules' with centrally controlled HVAC (Heating, Ventilation and Air Conditioning), the core concept of adaptive comfort resides in the idea of harmonizing the outdoor and indoor environment with natural ventilation, and to widen the comfort range of the occupants by increasing adaptive opportunities, to achieve comfort with less energy intensive practices. Passivhaus as a new sustainable housing typology shares features of both a naturally ventilated building, and a mechanically controlled building. It is designed on the premise that occupants are to accommodate its passive features, and adapt their perception of comfort into a more sustainable mean. The result however is far from ideal. Case study analysis of a diverse range of Passivhaus projects in the UK, argues that fundamentally Passivhaus principle is against the principle of adaptive comfort. The legacy of half a century's application of HVAC has already changed the occupants' expectations of comfort, which are now based as much on a normality of controlled environment as on seasonal and climatic variations. Many Passivhaus occupants are satisfied with or actively pursuing a narrow-ranged temperature setting (20±1˚C) that was promised by Passivhaus system throughout the whole year. Increased sensitivity to temperature change is experienced in a few cases, which seems to affect the occupants' demand for a rigid comfort zone in other scenarios. The study also shows the Passivhaus system is in danger of engaging more energy intensive technology for cooling with the escalation of global warming. To re-accommodate the adaptive comfort into the Passivhaus system, more attention needs to be paid from an architectural perspective rather than relying on spread sheet calculation and mechanical solutions.

Keywords: Passivhaus, adaptive comfort, HVAC

1. Introduction

...And I kind of thought that ... actually yes you can live in it and it's beautifully insulated but because there's no heating as such, that you live your life in a jumper... that was not how I thought, and I think that's kind of the image that Passivhaus had (Occupant describing when visiting a Passivhaus with 18 degree set point temperature)

The Thermal comfort model has been the guideline for built environmental design for the majority of the 20th century. It was undoubtedly established as the universally standard comfort model in Fanger's seminal (1970) Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD). The model has been reviewed many times since, as suggested by Shove(2003) '*maintaining indoor comfort standards, as enshrined in the codes produced by organisations like ASHRAE, commits society to dangerously unsustainable patterns of energy use*'. Ever since the 1970s, the comfort model in built environment research has experienced a major paradigm shift from PMV/PPD to the 'adaptive comfort' model (de Dear et al., 2013; Humphreys & Nicol, 1998). This model suggests that occupants of naturally ventilated buildings have a wider range of comfort and adaptive opportunities (such as operable windows providing better 'perceived comfort'). Nicol and Humpherys (2002) indicated that for these adaptation processes, people in naturally ventilated building tolerate a much wider range of temperature. In particular, the comfort temperature rose from approximately 17 ˚C to 29 ˚C together with the increase of outdoor temperature (from 13 ˚C to 32 ˚C).

The adaptive comfort model advocates individual control, natural ventilation and passive design. Therefore the 'free running' building was called for as opposed to a 'controlled building' (Baker, 1996). However despite the decline of PMV/PPD model and the static indoor environment it represents, the legacy of such comfort models and HVAC technology continues to affect the public's expectations of indoor environments, as well as social conventions, such as dress code.

Passive solar design is no novelty to the construction industry, but to increase energy efficiency and decrease the carbon footprint, the concept has been pushed further over the last 20 years to achieve higher standards. Passivhaus as a sustainable building methodology was developed as an extreme example of using solar energy and internal gains to achieve the best performance. However, Passivhaus is not equal to passive design. The main feature that differentiates Passivhaus from other low-energy housing is the application of MVHR (Mechanical Ventilation Heat Recovery). This system, as part of the new generation of sustainable technology however, shares surprisingly similar features with old fashioned HVAC – MVHR systems are centrally controlled, mechanically ventilated with an even temperature throughout the whole building, together with no individual control for each room and delayed responding time. Passivhaus buildings require an extremely air-tight environment, and in most cases, require a backup heating source (such as wood burner, combi boiler, electric heater etc.) to operate in winter in the UK. Most systems do not integrate mechanical cooling, and occupants have the opportunity to open windows in the summer to ventilate, though are encouraged to use a 'summer bypass' option to ventilate mechanically but without retaining the heat gain.

In this new type of semi - 'free running' building, it is unknown how the residents evaluate and achieve home comfort, and if this will still 'commit our future to a life time of high energy use' (de Dear & Brager, 1998; Shove, 2003).

2. Research Context

An insight into the perceived comfort and adaptive processes of Passivhaus occupants is required to better understand how people live in this building typology. Passivhaus projects in the UK have been studied, and the findings suggest a strong correlation between the social side of comfort and the participants' evaluation of their Passivhaus comfort (Zhao & Carter, 2015). The way occupants expect and evaluate these social aspects of comfort has affected the way they chose to (or not to) adapt to the new system. This paper will build upon previous analysis and will focus on the qualitative data to further understand the underlying issues in relation to the curious case of comfort in Passivhaus.

2.1 Comfort in HVAC society

Following the boom in the HVAC industry in the late 20th century, Cooper (1998) believed that air-conditioning had transformed the idea of 'comfort' into a sense of commodity that could be advertised (fig 1). The social comfort values HVAC brought into users' ideology have transferred their perception of comfort and the sense of control of external environment. As Chappell & Shove (2004) suggested, comfort is a 'matter of social and collective negotiation', Prins (1992) went further to suggest that comfort – related technologies are designed to 'control humans and in the process even out variations of culture and convention'. It's evident that the need to have a HVAC to achieve an unified indoor environment with a minimum temperature fluctuation and certain dress code, was both technically and socially constructed (Wilhite, 2009), which had led buildings to be seen as 'climatic fortresses' (Shove, 2003) that physically and culturally divide humans from their natural habitats.

Fig 1: Marketing of air conditioning poster

The 'Adaptive comfort model' was then introduced to regain the equilibrium by facilitating inhabitants with adaptive oppotunities to achieve a wider comfort range. CIBSE (2002) recommends a variation in temperature throughout different rooms - higher temperatures in living areas and lower in sleeping areas, ranging from 17 ˚C (bedroom) to 27 ˚C (bathroom). Nonetheless, temperature fluctuation is not the reason why Passivhaus appeals to the majority of the residents, rather the opposite.

2.2 Comfort in Passivhaus

Study of occupants' experience in Passivhaus was pioneered by Rohrmann (1994). According to Mlecnik (2012) who reviewed extensively early Passivhaus case studies in German language regarding occupants' experience, the majority of occupants living in Passivhaus expressed high levels of satisfaction in terms of comfort, however, recent research in Denmark and Sweden shows issues attributed to reduced occupants' comfort (eg cold floors; summer over heating; uneven temperature) exist in Passivhaus. (Brunsgaard, Knudstrup, & Heiselberg, 2012; Rohdin, Molin, & Moshfegh, 2014), these issues were viewed as negative, which counters the purpose of an MVHR system, designed to regulate temperature throughout the building. However, another case study claims uneven temperature isn't all that undesirable Paola (2013). The research compared the energy use of two very similar flats built to Passivhaus standard in the UK, the main difference is that one flat was operated by MVHR for the winter and most of the summer, the other was naturally ventilated (the resident never switched on MVHR), with non-uniform temperature throughout the house (15.5-21˚C between rooms). Both occupants regarded their home environment to be comfortable, and the naturally ventilated Passivhaus achieved lower energy consumption.

3. Methodology

This paper reports part of ongoing case study research using a grounded theory methodology aimed at developing new knowledge into how Passivhaus occupants adapt to the particular qualities of this building typology. A mixed methods approach was used to collect data from Passivhaus project across the UK. Online questionnaires were used to collect views on perceived comfort relative to Rybczynski's model (1987), and subsequently in-depth interviews were held with occupants of 13 Passivhaus case studies located across the UK (fig 2). Data analysis showed that environmental qualities are dominant factors of comfort to all 13 households with a focus on quantitative analysis of social perspectives of perceived comfort in Passivhaus (Zhao & Carter, 2015). This paper focuses on qualitative data gathered in the interviews, analysed using NVivo software to categorize and analyse themes originating from the residents' answers to the open interview questions. Categories that emerge from initial analysis of the data are organised in an iterative process. This step allows connections to be discovered between categories, and then organised to form a basic story line of cause and effect. Detailed study of each category and its subcategories to be understood to a measurable degree. This process uses the principle of variational sampling, which: '*relates categories in terms of the paradigm, focuses on uncovering and validating those relationships*.' (Strauss & Corbin, 1990; Zhao, 2014).

Fig 2: Geographical location of studied cases

4. Data Analysis

4.1 General Information

The studied cases include a social housing project - four semi-detached houses (House A, B, C and D), and eight private detached houses. The floor area ranges from approximately 80 sq.m to 297 sq.m. The majority of the houses accommodate two or three participants. In all cases, electricity is the primary energy consumption, only three households use gas in space heating and DHW (domestic hot water). Five households have photovoltaic panels installed which generate electricity and supply it to the national grid (Zhao & Carter, 2015).

4.2 Mechanically controlled comfort

All residents have gone through a learning period with the new mechanical system, and have the MVHR in operation for most of the time during their occupation. The mechanical systems installed throughout the households vary in the level of complexity and automatic operation. From a standard Passivhaus system with MVHR and a backup wood burner (House E), to an 'autonomous' Passivhaus with MVHR, highly intelligent control, composting toilet (House M), rainwater harvesting system (House G, K, M), PV electricity generation (House G, H, I, K, M). The thermal environment in these houses is carefully controlled by the mechanical systems. In the in-depth interviews, this mechanically controlled comfort has been positively reviewed by all of the residents, though interestingly, the baseline of comfort does not seem to be level between the households. Residents demonstrated different preferences for temperature settings, and how much temperature variation they enjoyed to have in the house. The following discussion examines the realities of a warm and 'even temperature' within the home and the effect on the residents' comfort perception.

Fig 3: Control panel of House G

5. Discussion

5.1 How not to 'live your life in a jumper'

Many interviewees chose the word 'even temperature' to describe their home environment. The majority thought of it as a positive attribute, as opposed to 'draughty', 'leaky windows' and 'radiant heat' (House E, I) experience in previous homes. Statements suggest that 'even temperature' enables residents to 'use the whole house' (House J), 'spend more time' in their home than before (House F). One resident went as far as to state that it made a more 'sociable lifestyle', and 'more open' (House H). When being asked to describe the comfort or any changes to their daily life occurred living in the Passivhaus, the majority of the occupants started with the changes in clothing, and showed appreciations of wearing less and lighter clothes indoors (House B, F, G, H, I, J, L), as a result of a relatively high thermostat setting (no less than 21 ˚C) and better internal gains. As the biggest indication of the comfort value for Passivhaus residents, this change in clothing is so desirable that failing to achieve it has almost put off one of the resident from building a Passivhaus:

...we went in [to a Passivhaus] and they (the residents) both had jumpers on, and that was the first thing that surprised me, she (the resident) said oh come in to the sitting room, we went in the kitchen and it was quite cool in there, she said ...we put the log fire on, specially because you were coming, so they obviously get used to live in ... whatever 17 degree or whatever it is. [R: The deviation was quite high, got 22 in the living room and 16 in the kitchen.] ...And I kind of thought that ... actually yes you can live in it and it's beautifully insulated but because there's no heating as such, that you live your life in a jumper... that was not how I thought, and I think that's kind of the image that Passivhaus had (House G).

5.2 MVHR(AC) Passivhaus

During the interview with House I, K, and M, the participants showed a decreased tolerance (or increased sensitivity) in temperature change and radiant heat. This result has a striking resemblance to the results of previous thermal comfort studies in mechanically ventilated building, where it was concluded that occupants of mechanically ventilated buildings are less tolerant of temperature fluctuation. (this ~~reflects the narrow ranged zone of mechanically ventilated environment – the PH system~~ resembles HVAC controlled buildings, suggesting that a Passivhaus system is very similar~~, does it make sense?~~) However curiously, for all three participants, this is a positive change, or 'an increased form of comfort' (House M). The occupant of House M continued to state that 'it doesn't mean you couldn't live somewhere else', but at the end said 'I wouldn't want to live in a house that wasn't a Passivhaus now, or indeed wasn't this [house]...'. Furthermore, as a result of being in a house so well insulated, the sense of outdoor weather condition has been altered. Two residents said they'd always go out and found themselves 'underdressed' (House I, G). This characteristic of Passivhaus appears to be a reverse from adaptive comfort model, where the comfort range of Passivhaus residents has been narrowed to 20±1˚C.

On the topic of cooling, when being asked if the house is over heated in the summer, many have said it can get 'really warm' (House A, B, I, M), or at least part of the house (House G), sometimes the temperature goes up to '27˚C' (House I). All residents feel the freedom and the need to open windows 'intelligently' to ventilate, stating that to ventilate through MVHR 'doesn't seem to be enough' (House A, I). Shading is the most common method to prevent overheating from solar gain amongst the residents other than opening windows, However, some have engaged in other mechanical means to cool the house down, such as using the 'summer bypass' feature of MVHR, or 'night time purging' – running MVHR to its full power in the night to ventilate (House A, M). The most interesting answer came from House G. As an engineer himself, the resident designed and built the house to Passivhaus standard, and devised it with a highly intelligent mechanical system, he intends to fill the post heater on MVHR with refrigerated water and turn it into an Air conditioning when it gets too hot in the future (House G).

6. Achieving (Slight) Variation – an Alternative

Despite the beloved 'even temperature' feature of Passivhaus, there seems to be a tendency towards a slight thermal variation between the rooms within a house. For a few residents, having 'all the same' temperature throughout the house is actually a downside (House J), and they would rather regain the individual control of the temperature for each room. This idea of a slight temperature variation was an expectation of the Passivhaus for residents that had been involved in designing the houses themselves (House G, H, M). In these three houses, the living rooms are positioned on the upper level while the bedrooms are put on the lower level to achieve a 'fairly even' but slightly deviated temperature between living area and bedrooms (fig 4.). Simple as it sounds, the standard of Passivhaus focuses so much on technical and mechanical solutions that architectural design and the human experience has been to some extent neglected. The design of these houses shows an alternative means to accommodate adaptive features into Passivhaus around how the spaces are used.

6. Conclusions

The combination of airtightness and MVHR provides Passivhaus with a highly controlled indoor environment, where temperature fluctuation is kept to the minimum. The potential for more intelligent and automatic controls suggest a future with even less adaptive opportunities. The influence of half a century's application and marketing of HVAC, has created social norms about home comfort such as dress code and the preference towards lighter clothing and bedding all year round. This is reflected in the Passivhaus system. In order not to 'live a life in a jumper', potential clients are attracted to the Passivhaus system for its narrow-ranged comfort zone, and the lived experience of Passivhaus has in turn narrowed it for its residents an expectation of thermal constancy, pushing the indoor environment further away from adaptive comfort. The study shows the Passivhaus system is in danger of engaging more energy intensive technology (HVAC) and behaviour (individual room heating) counter to the aim of very low energy use. To re-accommodate the adaptive comfort into the Passivhaus system, more attention needs to be paid from an architectural perspective rather than relying on spread sheet calculation and mechanical strategies.

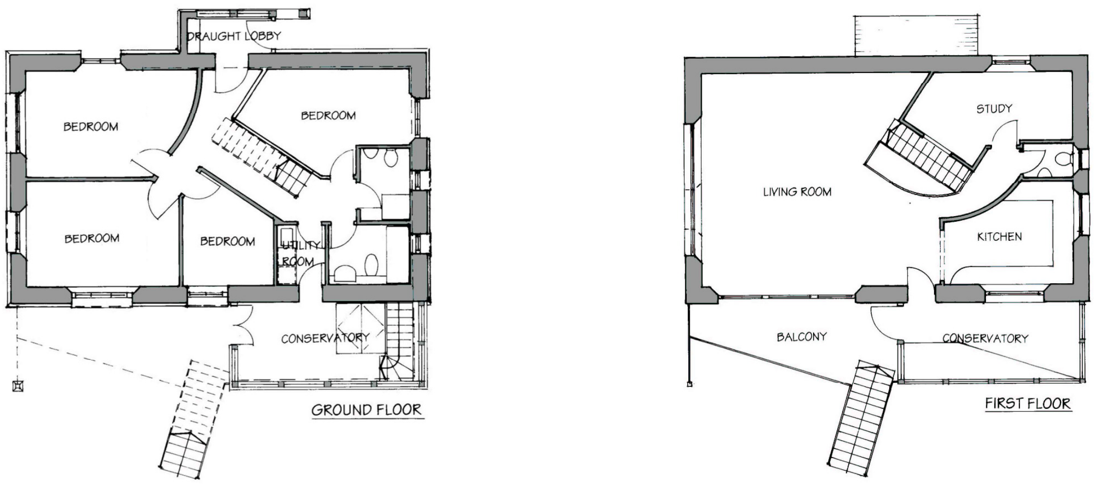

Fig 4: House M Layout plan with bedrooms on ground floor

7. Acknowledgments

Thanks to all the participants in this research, and including Jamie Carruthers of Dormont Estate, Professor Gokay Deveci, Ms. Kirsty Maguire and Mr. Grigor Mitchell to put me in touch with the residents.

8. References

Baker, N. (1996). Thermal comfort for free-running buildings. *Energy and Buildings, 23*(3), 175–182. doi: 10.1016/0378-7788(95)00942-6

Brunsgaard, C., Knudstrup, M.-A., & Heiselberg, P. (2012). Occupant Experience of Everyday Life in Some of the First Passive Houses in Denmark. *Housing, Theory and Society, 29*(3), 223-254. doi: 10.1080/14036096.2011.602718

Chappell, H., & Shove, E. (2004). *Comfort: A Review of Philosophies and Paradigms*. Lancaster University.

Chartered Institution of Building Services Engineers (CIBSE). Guide B1 Heating (2002).

Cooper, G. (1998). *Air-conditioning America: Engineers and the controlled environment, 1900-1960*.

de Dear, R. J., Akimoto, T., Arens, E. A., Brager, G., Candido, C., Cheong, K. W. D., . . . Zhu, Y. (2013). Progress in thermal comfort research over the last twenty years *Indoor Air. Dec* (Vol. 23, pp. 442).

de Dear, R. J., & Brager, G. S. (1998). Developing an adaptive model of thermal comfort and preference.

Humphreys, M. A., & Nicol, J. F. (1998). *Outdoor Temperature and Indoor Thermal Comfort: Raising the Precision of the Relationship for the 1998 ASHRAE Database of Field Studies.* Paper presented at the TRANSACTIONS-AMERICAN SOCIETY OF HEATING REFRIGERATING AND AIR CONDITIONING ENGINEERS.

Mlecnik, E., Schütze, T., Jansen, S. J. T., de Vries, G., Visscher, H. J., & van Hal, A. (2012). End-user experiences in nearly zero-energy houses. *Energy and Buildings, 49*, 471-478. doi: 10.1016/j.enbuild.2012.02.045

Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings, 34*(6), 563–572. doi: 10.1016/S0378-7788(02)00006-3

Paola, S. (2013). A Natural Ventilation Alternative to the Passivhaus Standard for a Mild Maritime Climate. *Buildings*(1), 61.

Prins, G. (1992). On condis and coolth. *Energy and Buildings, 18*(3-4), 251-258.

Rohdin, P., Molin, A., & Moshfegh, B. (2014). Experiences from nine passive houses in Sweden – Indoor thermal environment and energy use. *Building and Environment, 71*, 176-185. doi: 10.1016/j.buildenv.2013.09.017

Rohrmann, B. (1994). Sozialwissenschaftliche Evaluation des Passivhauses in Darmstadt. *Passivhaus-Bericht Nr. 11; Institut Wohnen und Umwelt*.

Rybczynski, W. (1987). *Home: A short history of an idea*.

Shove, E. (2003). *Comfort, cleanliness and convenience : the social organization of normality*. Oxford: Berg.

Strauss, A. L., & Corbin, J. M. (1990). *Basics of qualitative research : grounded theory procedures and techniques*. Newbury Park, Calif. ; London: Sage Publications.

Wilhite, H. (2009). The conditioning of comfort. *Building Research & Information. Jan2009, 37*(1), 84. doi: 10.1080/09613210802559943

Zhao, J. (2014). *Applying Grounded Theory Methodology with Mixed Methods in Occupant Energy Behaviour Research*. Paper presented at the The International Academic Forum (IAFOR) 2014, Brighton, UK.

Zhao, J., & Carter, K. (2015). *Perceived Comfort and Adaptive Process of Passivhaus 'Participants'*. Paper presented at the SEB 15, Lisbon.